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# Orbit Transfer Vehicle(OTV) Engine Phase "A" Study

**Contract NAS 8-32999**  
**Bi-Monthly Status Report 32999-M1**  
**15 August 1978**

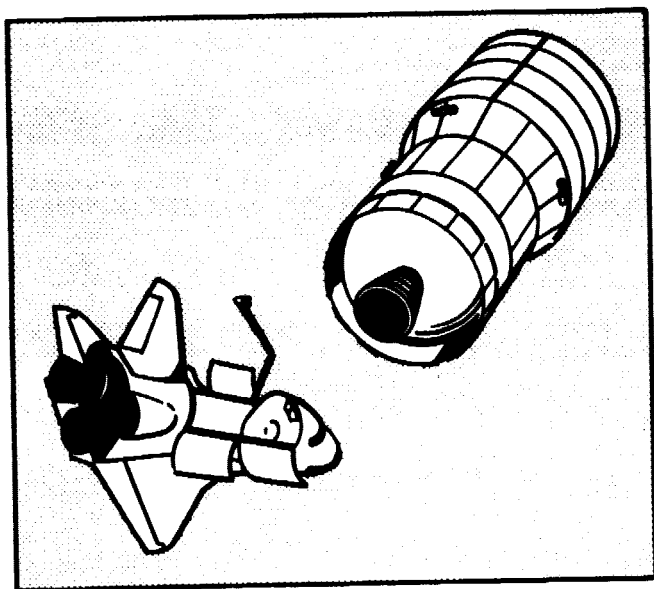
(NASA-CR-150796) ORBIT TRANSFER VEHICLE  
(OTV) ENGINE PHASE A STUDY Bi-Monthly  
Status Report, 10 Jul. 1978 - 31 Jul. 1978  
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**Prepared for:**

**NASA - George C. Marshall Space Flight Center**



Aerojet  
Liquid Rocket  
Company

Report 32999-M1

15 August 1978

ORBIT TRANSFER VEHICLE (OTV) ENGINE PHASE "A" STUDY

Bi-Monthly Status Report No. 1

10 July 1978 to 31 July 1978

Contract NAS 8-32999

Prepared for:

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George C. Marshall Space Flight Center  
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## FOREWORD

This bi-monthly status report is submitted for the Orbit Transfer Vehicle (OTV) Engine Phase "A" Study per the requirements of Contract NAS 8-32999, Data Procurement Document No. 559, Data Requirement No. MA-02. This work is being performed by the Aerojet Liquid Rocket Company for the NASA-Marshall Space Flight Center. The study authority to proceed date was 10 July 1978.

This study program consists of parametric trades and system analysis which will lead to conceptual designs of the OTV engine for use by the OTV systems contractor.

The NASA/MSFC COR is Mr. D. H. Blount. The ALRC Program Manager is Mr. L. B. Bassham, and the Study Manager is Mr. J. A. Mellish.



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## I. INTRODUCTION

The Space Transportation System (STS) includes an Orbit Transfer Vehicle (OTV) that is carried into low Earth orbit by the Space Shuttle. The primary function of this OTV is to extend the STS operating regime beyond the Shuttle to include orbit plane changes, higher orbits, geosynchronous orbits and beyond. The NASA and DOD have been studying various types of OTV's in recent years. Data have been accumulated from the analyses of the various concepts, operating modes and projected missions. The foundation formulated by these studies established the desirability and the benefits of a low operating cost, high performance, versatile OTV. The OTV must be reusable to achieve a low operating cost. It is planned that an OTV have an Initial Operating Capability (IOC) in 1987.

The OTV has as a goal the same basic characteristics as the Space Shuttle, i.e., reusability, operational flexibility, and payload retrieval along with a high reliability and low operating cost. It is necessary to obtain sufficient data, of a depth to assure credibility, from which comparative systems analyses can be made to identify the development, costs, and program requirements for OTV concepts. The maximum potential of each concept to satisfy the mission goals will be identified in the OTV systems studies to be initiated in FY-79.

An assessment of the above factors will be made by the NASA to determine the candidate approaches for matching the OTV concepts to mission options within resource and schedule requirements. This study will provide the necessary data on OTV engine concept(s) based upon 1980 technology which is required to objectively select, define, and design the preferred OTV engine, and is being conducted in very close concert with the NASA.

## I, Introduction (cont.)

The major objective of this Phase "A" engine study is to provide design and parametric data on the OTV engine for use by NASA and the OTV systems contractors. These data and the systems analyses will ultimately lead to the identification of the OTV engine requirements so that the conceptual design phase can be initiated. Specific study objectives are:

- ° Review the OTV engine requirements identified in the statement of work, make recommendations and iterate with NASA/MSFC.
- ° Conduct trade studies and system analyses necessary to define the engine concept(s) which meets the OTV engine requirements.
- ° Generate parametric OTV engine data and provide this data in suitable format for use by the OTV system contractors.
- ° Prepare a final report at the completion of the study which documents the technical and programmatic assessments of the OTV engine concepts studied.

To accomplish the program objectives, a study program consisting of seven major technical tasks and a reporting task is being conducted. These tasks are:

- ° Task I: Engine Requirement Review
- ° Task II: Engine Concept Definition
- ° Task III: Parametric Engine Data
- ° Task IV: Engine Off-Design Operation
- ° Task V: Work Breakdown Structure
- ° Task VI: Programmatic Analysis and Planning
- ° Task VII: Cost Estimate
- ° Task VIII: Reports Requirements

## II. SUMMARY

This first bi-monthly status report covers the period from the initiation of the contract (10 July 1978) to 31 July 1978.

Initial efforts were placed upon Tasks I, II and VIII. The study program schedule along with major milestones is shown on Figure 1.

An orientation briefing on the planned study was given at NASA/MSFC prior to the initiation of the contract on 28 June 1978. This briefing and associated documentation covered the study organization, objectives, schedule, manhours, overall study logic and detailed task descriptions.<sup>(1)</sup>

A study plan providing written documentation on those items covered in the orientation briefing and updated to reflect the agreements reached at this meeting was submitted to NASA/MSFC.<sup>(2)</sup>

The review of the engine requirements set forth in the statement of work was initiated and trade studies on staged combustion, expander and gas generator engine cycles are being conducted to define an engine concept which meets the OTV engine requirements. The performance requirements favor a staged combustion cycle engine although none of the engine cycles can satisfy the performance requirements over the total thrust and stowed engine length ranges specified in the statement of work. It is anticipated that the results of these initial two tasks will be reviewed at NASA/MSFC in early September.

(1) Orbit Transfer Vehicle (OTV) Engine Phase "A" Study, Orientation Briefing, ALRC Report No. 2787:031, 28 June 1978.

(2) Orbit Transfer Vehicle (OTV) Engine Phase "A" Study, Study Plan, Contract NAS 8-32999, ALRC Report DPD559; MA-01, 24 July 1978.



TASK	PROGRAM MONTH						
	JULY	AUG	SEPT	OCT	NOV	DEC	JAN
I. ENGINE REQUIREMENT REVIEW	▾						
II. ENGINE CONCEPT DEFINITION	▾	▾					
III. PARAMETRIC ENGINE DATA		▾	▾	▾	▾		
IV. ENGINE OFF-DESIGN OPERATION				▾	▾		
V. WORK BREAKDOWN STRUCTURE		▾	▾				
VI. PROGRAMMATIC ANALYSIS & PLANNING			▾	▾	▾		
VII. COST ESTIMATE					▾	▾	
VIII. REPORTING							
A. STUDY PLAN	▾						
B. BI-MONTHLY STATUS REPORTS		▾		▾			
C. SUBMIT PRELIMINARY WBS	▾						
D. REVIEWS							
1. ORIENTATION BRIEFING	▾ (1)						
2. FINAL BRIEFING							▾
E. FINAL REPORT							▾

(1) 28 June 1978

Figure 1. Study Program Milestone Schedule

### III. TECHNICAL PROGRESS

#### A. TASK I: ENGINE REQUIREMENT REVIEW

Engine performance/weight sensitivities were derived using vehicle weight scaling equations provided by NASA/MSFC and the mission  $\Delta V$ 's shown in Tables 26 and 27 of NASA TMX-73394.

The mission  $\Delta V$ 's used for the All Propulsive Orbit Transfer Vehicle (APOTV) and the Aeromaneuvering Orbit Transfer Vehicle (AMOTV) are:

$$\text{APOTV: } \Delta V = 27874 \text{ ft/sec}$$

$$\text{AMOTV: } \Delta V = 20432 \text{ ft/sec}$$

These  $\Delta V$ 's were considered to apply at a nominal engine thrust level of 20,000 lbs.

The vehicle weight scaling equations are:

APOTV:

$$W_g = 8246 + 0.09987 (W_p - 83255) + 1.1 W_{\text{ENG}}$$

AMOTV:

$$W_g = 8975 + 0.09882 (W_p - 72,000) + 1.1 W_{\text{ENG}}$$

For both vehicle concepts:

$$W_p = \left[ 1 - e^{-\frac{\Delta V}{g I_{\text{sv}}}} \right]$$

### III, A, Task I: Engine Requirement Review (cont.)

here:

- $I_{sv}$  = engine vacuum specific impulse
- $W_g$  = stage cutoff weight (less payload)
- $W_i$  = initial ignition weight = 97,300 lbs for 100,000 lb payload shuttle per S.O.W.
- $W_p$  = propellant weight
- $W_{ENG}$  = engine weight

The derived performance/weight sensitivities for the baseline round trip mission for a 100K shuttle are:

APOTV:

$$\frac{\Delta W_{PL}}{\Delta W_{ENG}} = -1 \text{ lb/lb}$$

$$\frac{\Delta W_{PL}}{\Delta I_{sv}} = 60 \text{ lb/sec}$$

AMOTV:

$$\frac{\Delta W_{PL}}{\Delta W_{ENG}} = -1 \text{ lb/lb}$$

$$\frac{\Delta W_{PL}}{\Delta I_{sv}} = 73 \text{ lb/sec}$$

$W_{PL}$  = payload weight

The equations and sensitivities shown will be used to assess the impacts of the requirements and to conduct the necessary engine trades.



### III, A, Task I: Engine Requirement Review (cont.)

The effect of the requirement for a service life of 300 start/shutdown cycles between overalls upon the maximum engine operating pressure was established. The analysis was based upon past study results and current projections as shown on Figure 2. The OOS study<sup>(3)</sup>, conducted in 1971, was conservative compared to today's technology. However, the chamber pressure trend with thrust was used to make the current estimation. This results in life limit chamber pressures of:

<u>Thrust, Klb</u>	<u>Max Pc, psia</u>
10	1500
20	2000
30	2350

These values will be updated by more rigorous analyses during the course of this study. However, these preliminary values will be used to assist in the concept definition task.

The sensitivity of the engine design point (i.e., thrust chamber pressure and nozzle area ratio) to the performance requirements specified in the statement of work was also evaluated. The results of this analyses are shown on Table I. For these performance calculations it was assumed that the engine was a staged combustion or expander cycle (i.e., no turbine exhaust bleed flow loss). The table shows that the minimum required pressure for a 10K engine exceeds that required to meet the chamber life requirement. Therefore, a performance decrease at the 10K thrust level or a chamber life reduction must be accepted. This study

(3) Orbit-to-Orbit Shuttle Engine Design Study, Final Report, Contract F04611-71-C-0040, AFRPL TR-72-45, ALRC, May 1972.

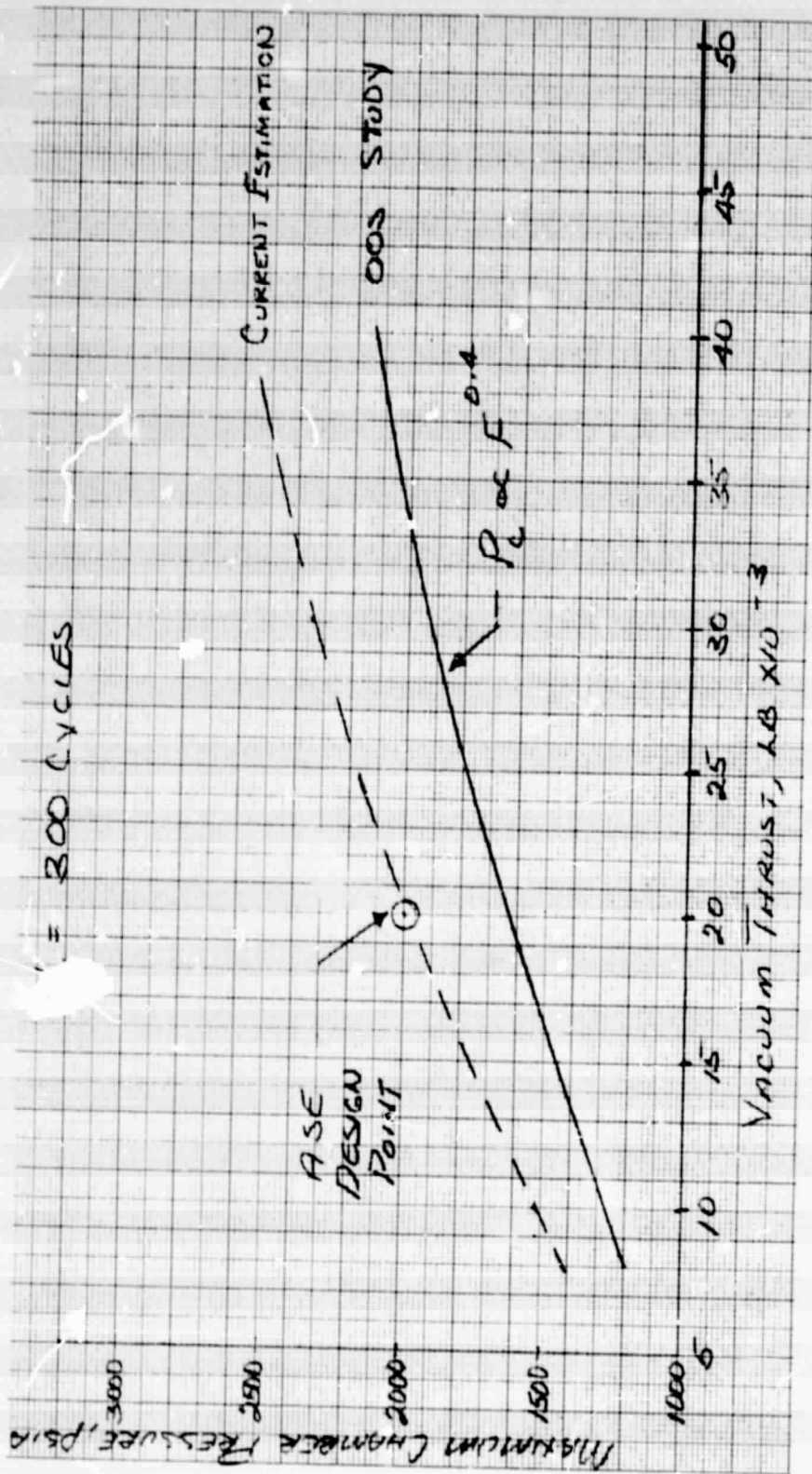


Figure 2. Maximum Chamber Pressure for Chamber Life Cycle Requirement vs Thrust

TABLE I

DESIGN POINT SENSITIVITY TO  
PERFORMANCE REQUIREMENTS

Engine Mixture Ratio = 6.0

Engine Vacuum Thrust, Klb	Engine Stowed Length, inches	Minimum Required Specific Impulse, sec	Required Nozzle Area Ratio	Minimum Required Chamber Pressure, psia
10	50	480	1000	3500
↓	60	↓	↓	3332
	70	↓	↓	3124
20	50	473	537	1911
↓	60	↓	564	1328
	70	↓	576	958
30	50	472	415	2246
↓	60	↓	465	1652
	70	↓	477	1191

### III, A, Task I: Engine Requirement Review (cont.)

will assess the performance reduction. The chamber pressures at the other thrusts and stowed lengths can be increased to the chamber life limit values. This will result in higher than the minimum required performance. At a stowed length of 50 inches the chamber pressures at 20K and 30K lbs thrust are, for practical purposes, at the chamber life limit values.

The table also shows that performance is the primary chamber pressure "driver" at the 10K thrust level. However, when performance is almost equal (20K and 30K lbs thrust), the engine envelope is the governing requirement. This is why the chamber pressure at a thrust level of 30K is greater than that at 20K. The higher thrust engine is more difficult to fit in the envelope even though the performance requirement is slightly lower.

Expander cycle engines using existing chamber design techniques are power balance limited (see Section III,B). This cycle can only meet the performance requirement at a thrust level of 20,000 lbs thrust and a stowed length of 70 inches. Other factors such as, the man-rating requirement and development simplicity will be evaluated in comparing the staged combustion versus expander cycles.

### B. TASK II: ENGINE CONCEPT DEFINITION

Preliminary engine system analyses were conducted on the staged combustion, expander and gas generator engine cycles. Simplified schematics of the cycles analyzed are shown on Figures 3, 4 and 5.

Pump discharge pressure requirements for 20,000 lb thrust engines operating at an engine mixture ratio of 6.0 are shown on Figures 6 and 7. Figure 6 displays the hydrogen pump discharge pressure as a

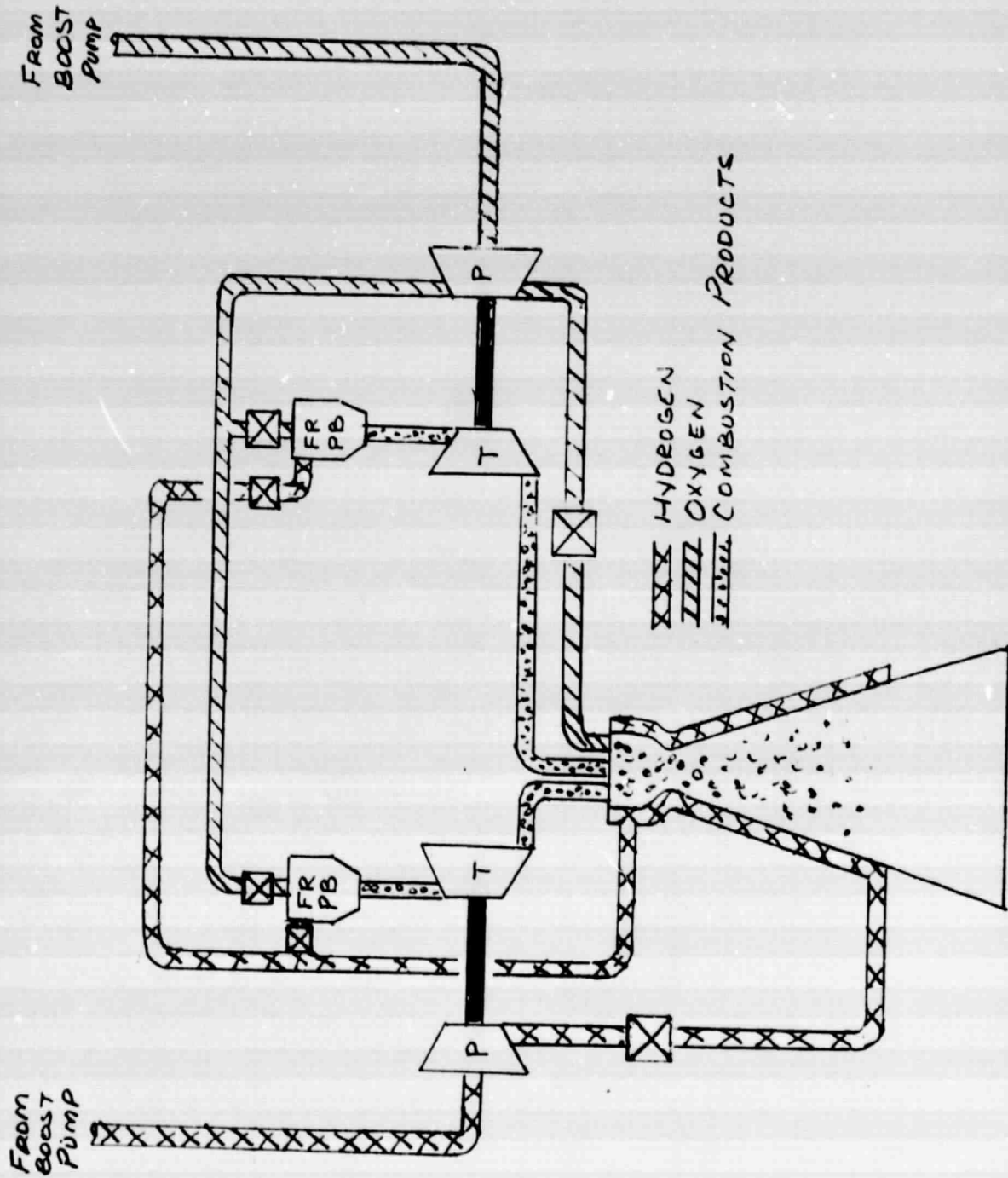


Figure 3. Dual Fuel-Rich Preburner Staged Combustion Cycle

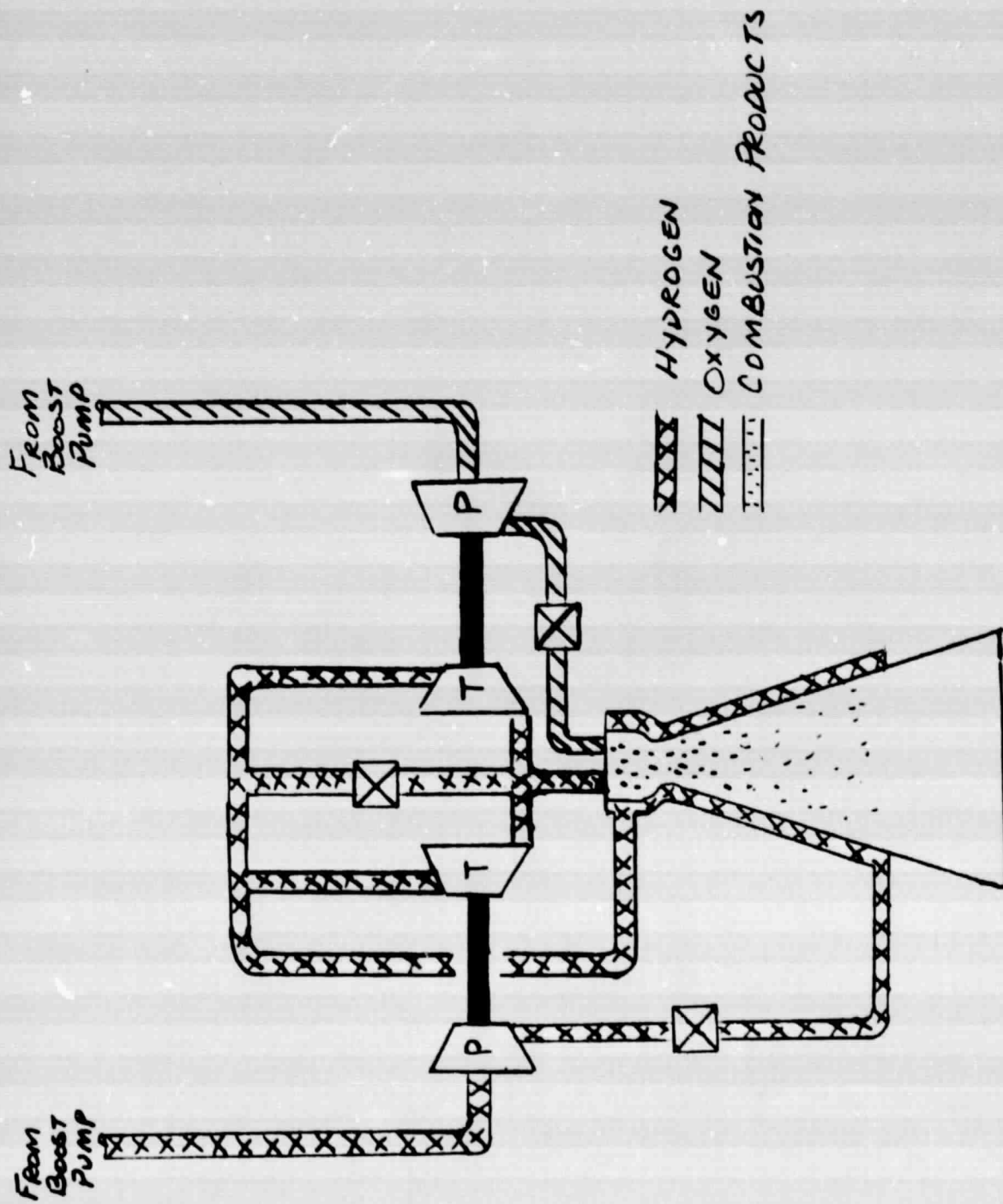


Figure 4. Expander Cycle



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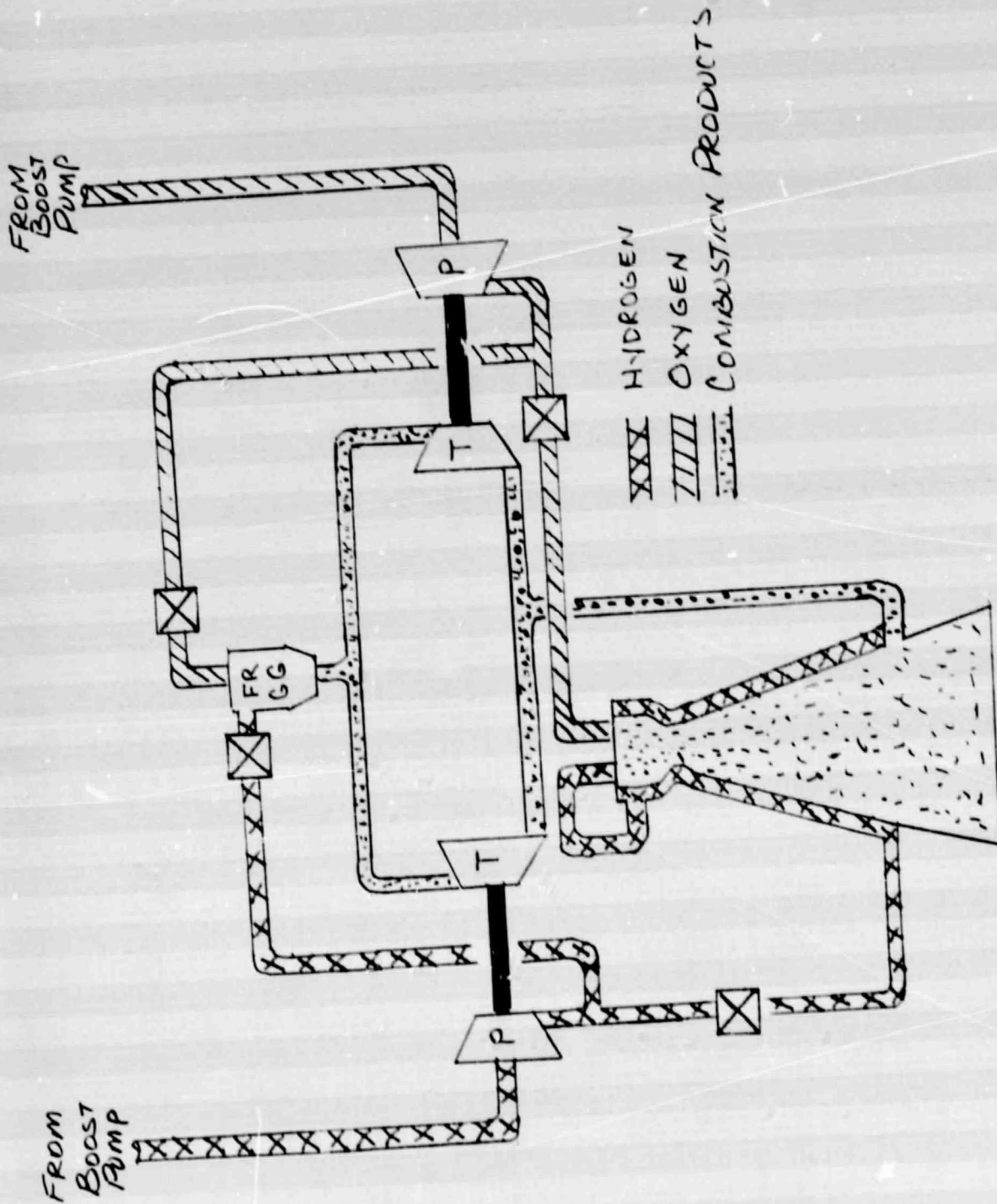


Figure 5. Gas Generator Cycle

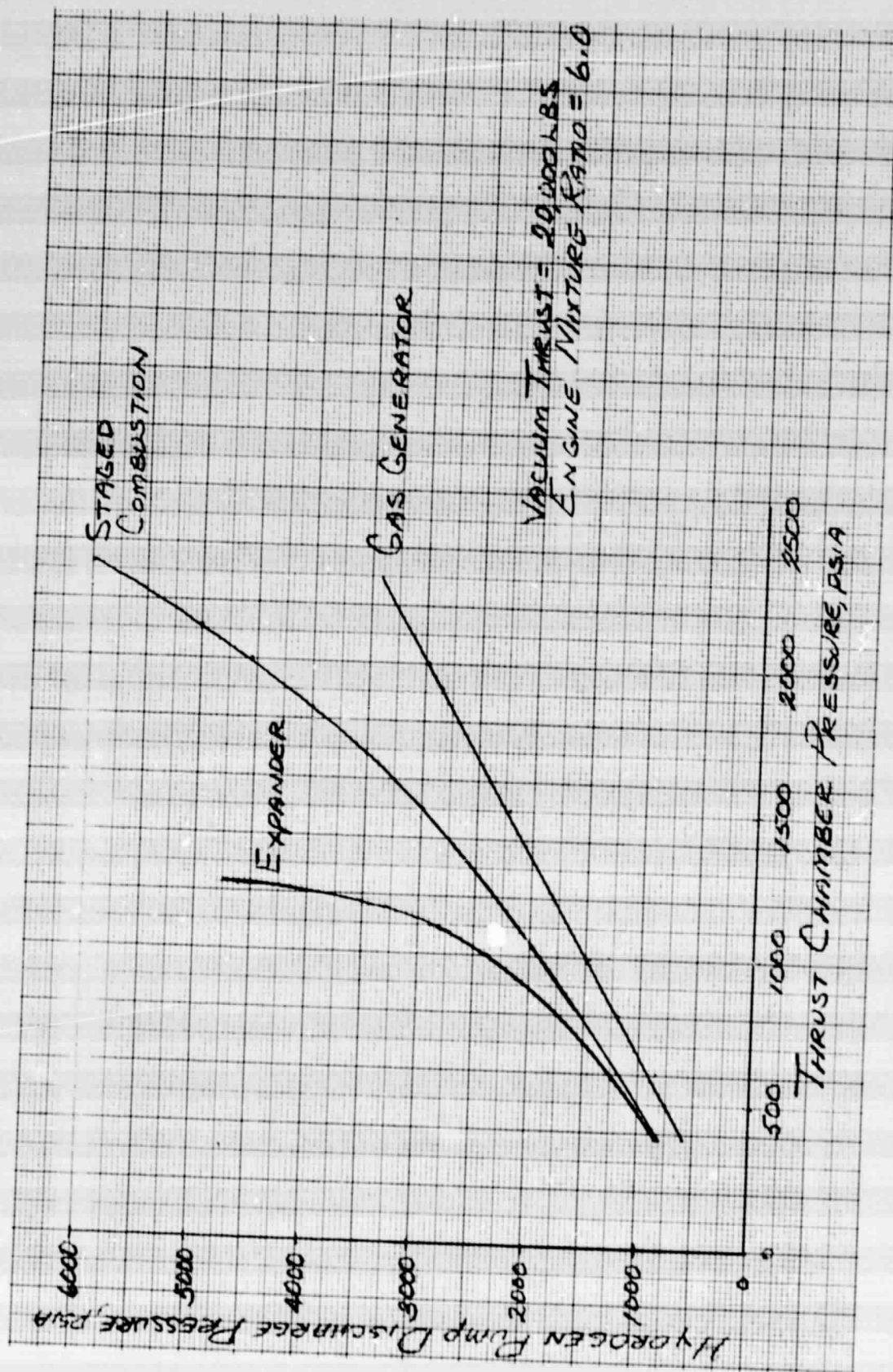


Figure 6. Hydrogen Pump Discharge Pressure Requirements for Various Engine Cycles



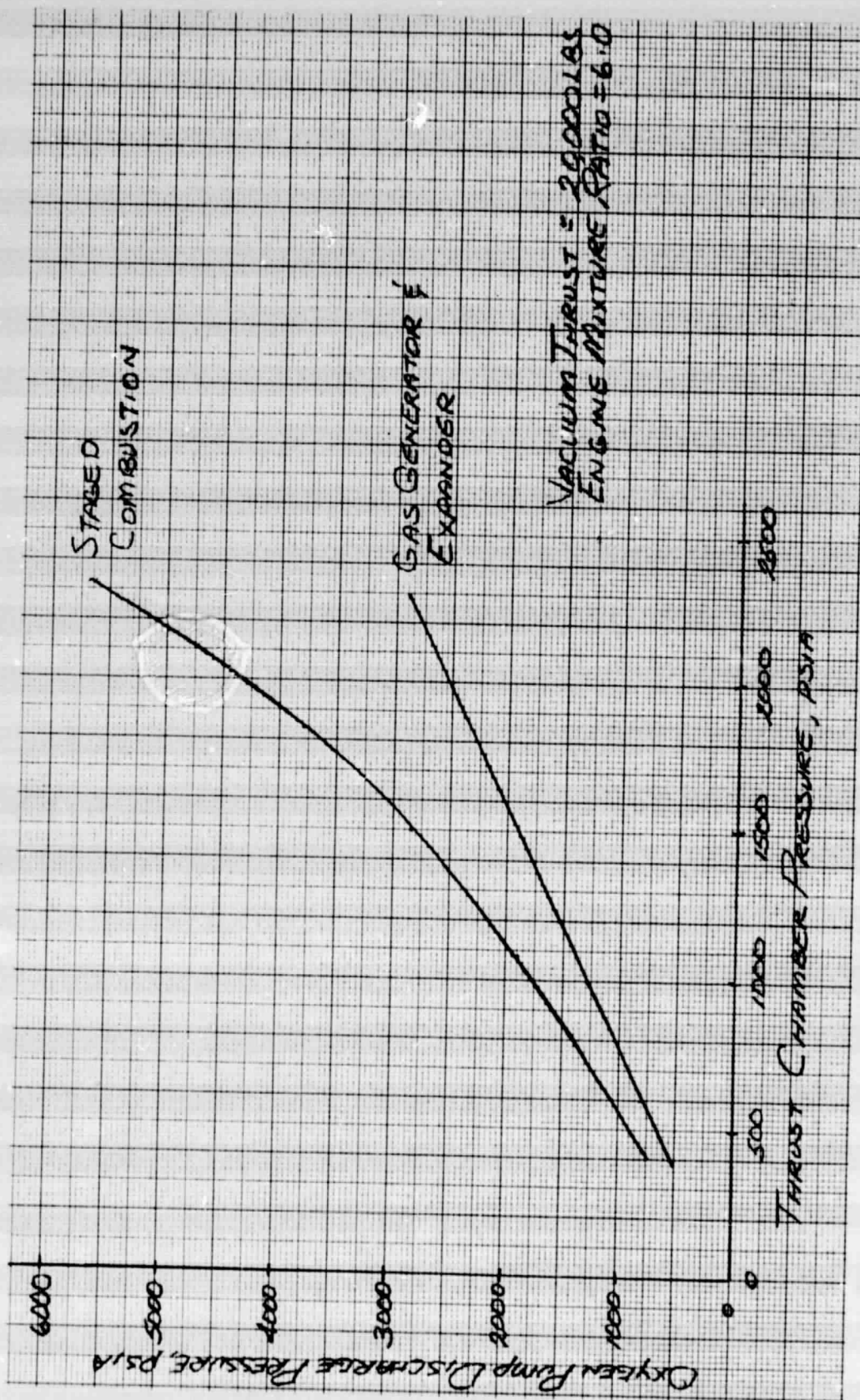


Figure 7. Oxygen Pump Discharge Pressure Requirements for Various Engine Cycles

### III, B, Task II: Engine Concept Definition

function of thrust chamber pressure and shows that the expander cycle engine is power balance limited. Neither the staged combustion or gas generator cycles are power balance limited for the range of chamber pressures analyzed. Hence, the maximum attainable chamber pressure for these cycles is chamber life limited (Figure 2). Figure 7 shows that the staged combustion cycle engine requires significantly higher oxidizer pump discharge pressures than the expander and gas generator cycles.

The power balances shown were conducted for a turbine inlet temperature of 1860°R for both the staged and gas generator cycles. This value was selected in the OOS study to meet the 300 cycle life limit. The OOS and RL-10 study<sup>(4)</sup> results were used in analyzing the expander cycle. The coolant outlet temperature (turbine inlet temperature) is shown as a function of thrust on Figure 8. This data was used to conduct the expander cycle power balances at other thrust levels. The result of this analysis is shown on Figure 9. This figure shows the approximate power balance chamber pressure limit as a function of thrust for the expander cycle engine. This limit is defined as 80% of the chamber pressure value at which the hydrogen pump discharge pressure becomes asymptotic.

Figure 10 compares the performance for each of the three cycles considered. For this preliminary analyses a baseline area ratio of 400 was selected at thrust chamber pressure of 2000 psia. This results in a delivered performance value of 473 secs for the staged combustion cycle engine. The attainable area ratio at other chamber pressures was then assumed directly proportional to chamber pressure since the available enveloped is fixed. The delivered performance values have also been estimated as 97.4% of

(4) Design Study of RL-10 Derivatives, Final Report, Volume II, Engine Design Characteristics, Contract NAS 8-23989, Report FR-6011, Pratt & Whitney Aircraft, 15 December 1973.

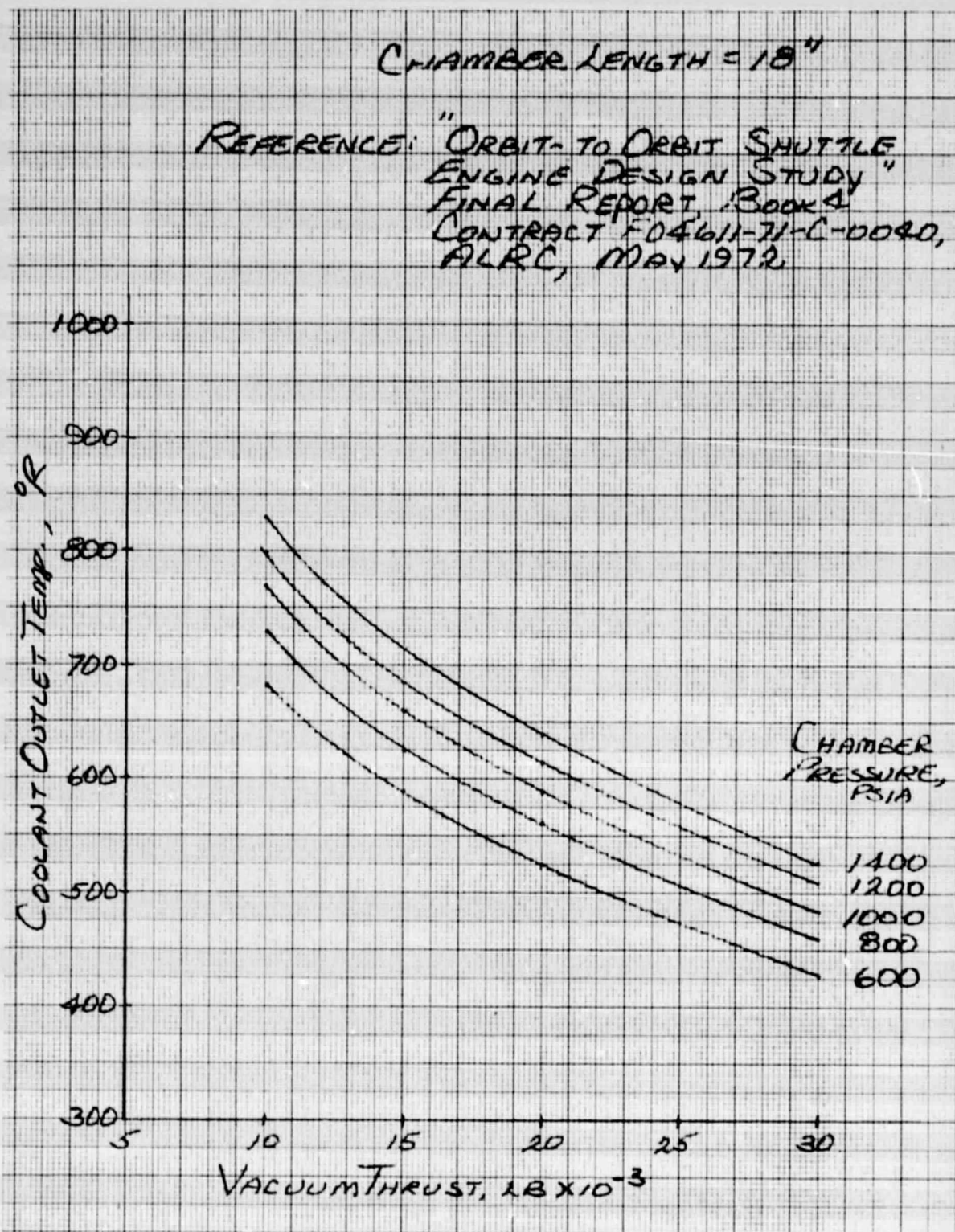


Figure 8. Effect of Thrust Upon Coolant Outlet Temperature  
for an Expander Cycle Engine



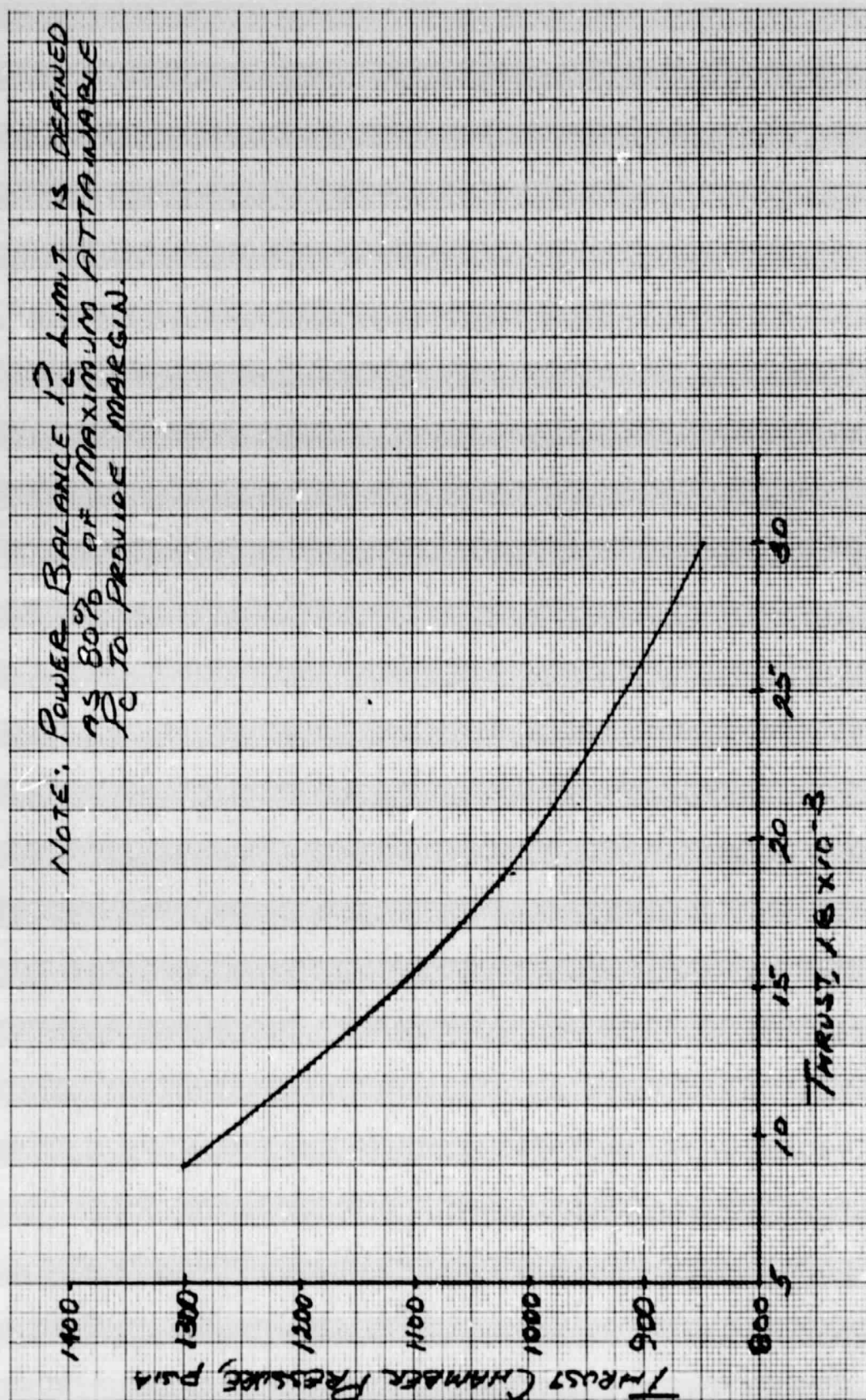


Figure 9. Expander Cycle Power Balance Chamber Pressure Limits

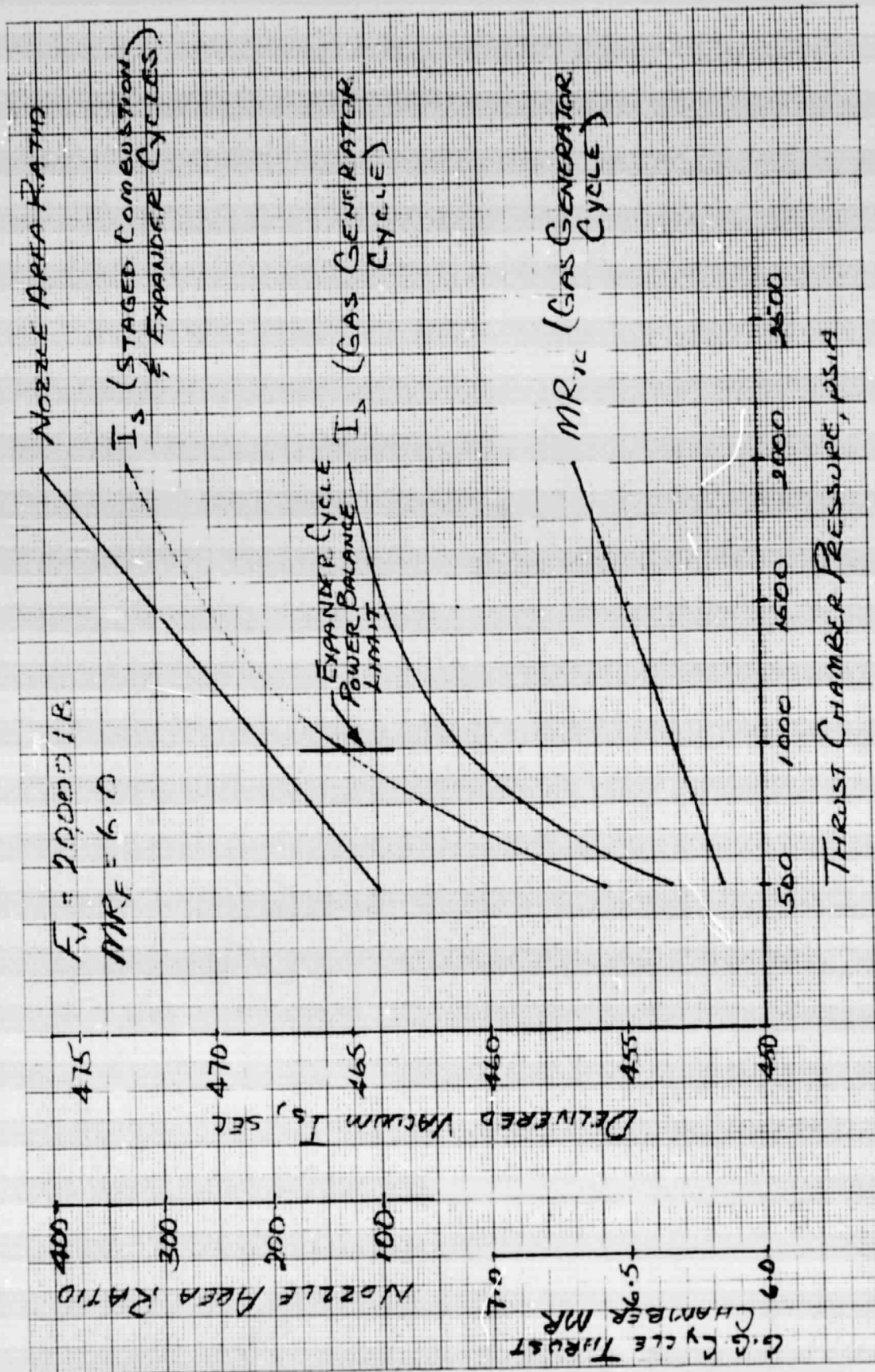


Figure 10. Preliminary Engine Cycle Performance Comparison

### III, B, Task II: Engine Concept Definition (cont.)

theoretical ODE. This may be slightly high at the lower chamber pressures but is accurate enough for relative comparisons.

The figure shows that the gas generator cycle engine performance at 2000 psia (chamber life limit) is approximately equal to that of an expander cycle at its power balance limit of 1000 psia. At these design chamber pressures, the gas generator cycle engine weighs 10% more than the expander cycle engine. At the same operating chamber pressure, the weights of these two engine cycles are approximately equal. Therefore, the gas generator cycle engine does not have any weight/performance advantage over an expander cycle. The gas generator cycle engine performance loss (difference between the two  $I_s$  lines on the figure) consists of both the bleed flow loss and the ODE loss associated with the thrust chamber mixture ratio shift.

The staged combustion cycle engine, although higher performing, weighs approximately 20% more (100 lbs) than the expander cycle engine when each are taken at their maximum operating chamber pressure. Preliminary engine cycle weight comparisons are shown on Table II.

#### C. TASK III: PARAMETRIC ENGINE DATA

No scheduled activity.

#### D. TASK IV: ENGINE OFF-DESIGN OPERATION

No scheduled activity.

TABLE II  
PRELIMINARY ENGINE CYCLE WEIGHT COMPARISONS

	<u>Staged</u>	<u>Cycle Expander</u>	<u>G.G.</u>
Thrust, lb	20000	20000	20000
Chamber Pressure, psia	2000	1000	2000
Nozzle Area Ratio	400	200	400
Engine Mixture Ratio	6.0	6.0	6.0
Chamber Length, in.	8.0	18.0	14.0
Engine Dry Weight*, lb	579	473	534

\*Does not include the weight of an engine controller.



### III, Technical Progress (cont.)

#### E. TASK V: WORK BREAKDOWN STRUCTURE

A preliminary WBS was structured in concert with NASA in meetings following the orientation briefing. The WBS will be updated as necessary to meet the needs of the engine concept selected in Task I!.

#### F. TASK VI: PROGRAMMATIC ANALYSIS AND PLANNING

No scheduled activity.

#### G. TASK VII: COST ESTIMATE

No scheduled activity.

#### H. TASK VIII: REPORTS REQUIREMENTS

The study plan was transmitted to NASA/MSFC on 31 July 1978 per the requirements DPD 559, DR MA-01.

### IV. CURRENT PROBLEMS

No technical or administrative problems were encountered during this reporting period.

### V. WORK PLANNED

The work planned for the next two months is discussed for each task in the paragraphs which follow.



## V, Work Planned (cont.)

### A. TASK I: ENGINE REQUIREMENT REVIEW

Complete the review of the OTV engine requirements, make recommendations and iterate with NASA/MSFC.

### B. TASK II: ENGINE CONCEPT DEFINITION

Complete the tradeoff analyses to select an engine cycle and concept which best meets the engine requirements. Conduct a review of the trades, rationale and selection with NASA.

### C. TASK III: PARAMETRIC ENGINE DATA

Initiate the technical effort to define the engine performance, weight and envelope parametric data for the selected engine concept.

### D. TASK IV: ENGINE OFF-DESIGN OPERATION

No activity scheduled.

### E. TASK V: WORK BREAKDOWN STRUCTURE

Update the WBS for the selected engine concept. Review the WBS dictionary and iterate with NASA.

### F. TASK VI: PROGRAMMATIC ANALYSIS AND PLANNING

Initiate effort to define the engine DDT<sup>FF</sup> schedule and component test requirements.

V, Work Planned (cont.)

G. TASK VII: COST ESTIMATE

No activity scheduled.

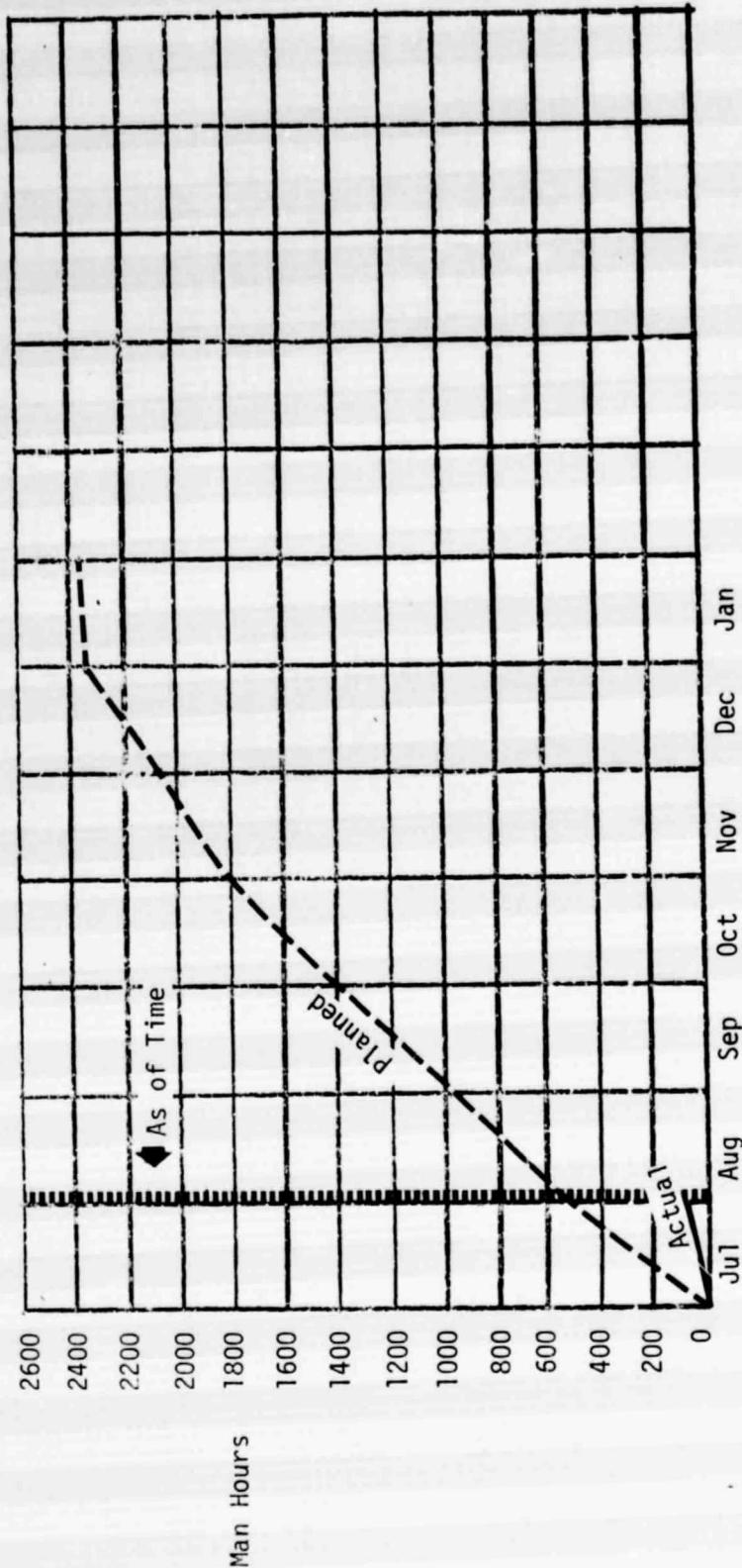
H. TASK VIII: REPORTS REQUIREMENTS

Conduct the engine requirement and engine concept definition review with NASA.

VI. MAN-HOUR EXPENDITURES

The planned vs actual man-hours expended during this reporting period are shown on Figure 11. The low actual expenditure rate reflects the mid-July rather than a 1 July start of the technical effort and a reporting period of only 19 days. All planned activities have been initiated and the engineering personnel are on-board.

National Aeronautics and Space Administration Contractor Man Hour Management Report		Report for Month Ending: 30 July 1978 (19 days)	
To: Financial Management Office George C. Marshall Space Flight Center, NASA Marshall Space Flight Center, AL 35812	From: Aerojet Liquid Rocket Co. Post Office Box 13222 Sacramento, California 95813	Type: CPFF	Contract No. NAS 8-32999
Contract Description Scope of Work: Orbit Transfer Vehicle Engine Study, Phase A	Auth. Contr. Rep.	Date:	



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Figure 11. Contractor Man Hour Management Report